Bounds on unparticle interactions with the electroweak sector

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Scott Kathrein, Simon Knapen, Matt Strassler
Rutgers University

Hidden CFT sectors (unparticles)

Motivation

- Calculability
- New signatures
- bonus: some model independence

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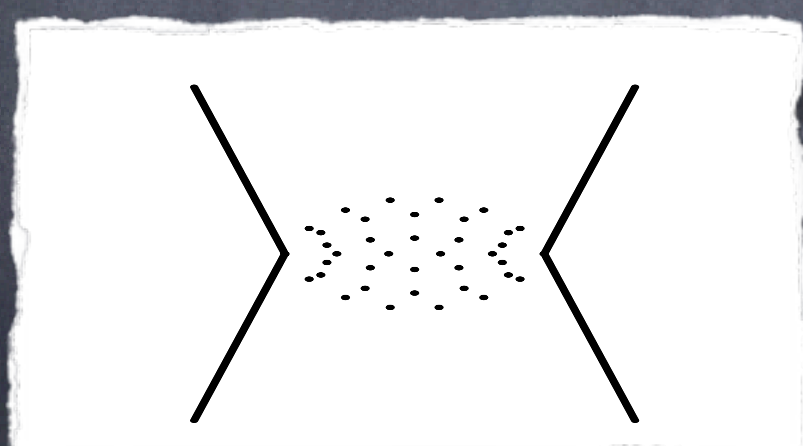
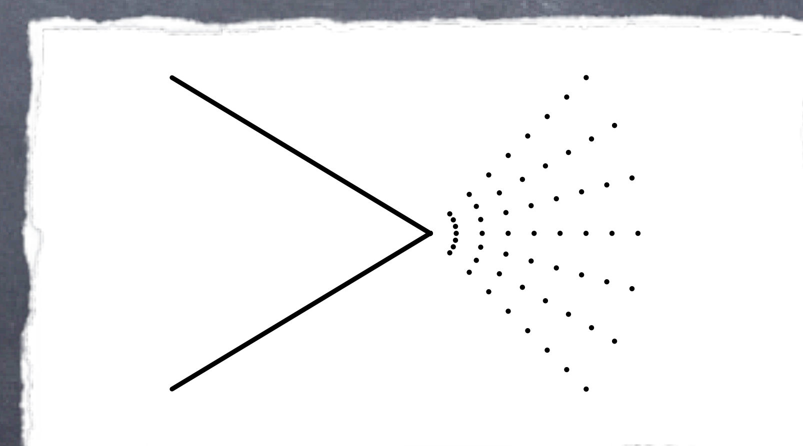
Signatures





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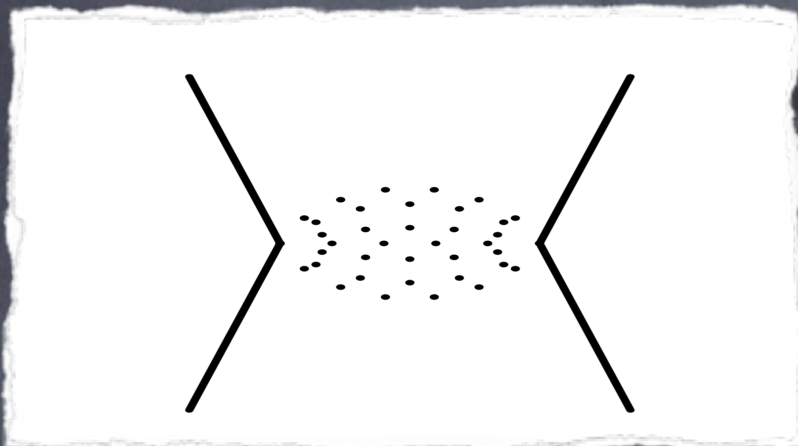
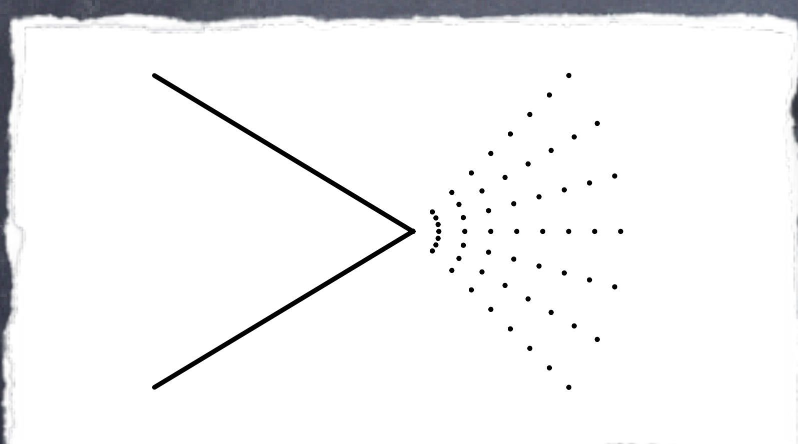
Calculability



$$\frac{C}{(x_1 - x_2)^{2\Delta}} \to iA_\Delta \theta(p_0)\theta(p^2)(p^2 + i\epsilon)^{\Delta-2}$$



H. Georgi (2007)

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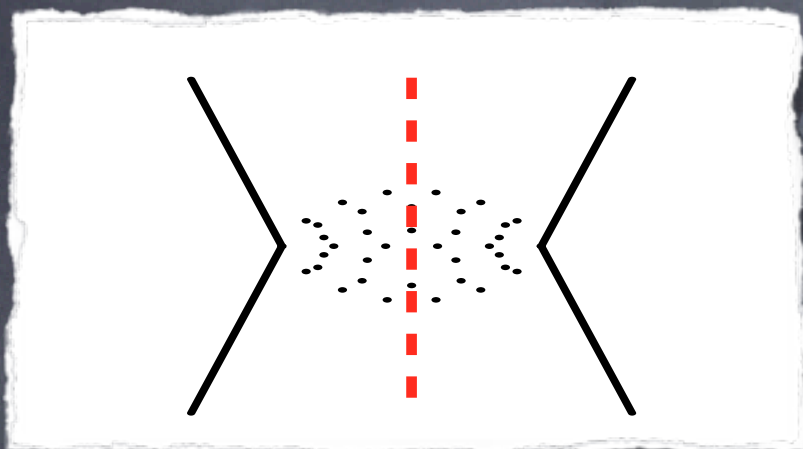
Calculability



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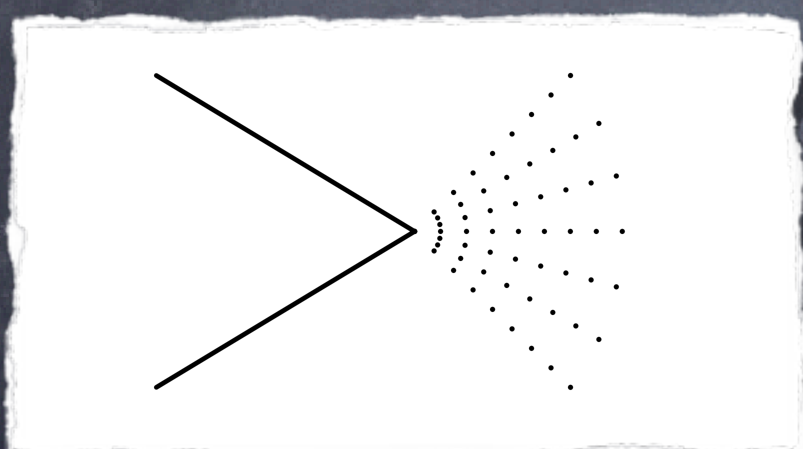

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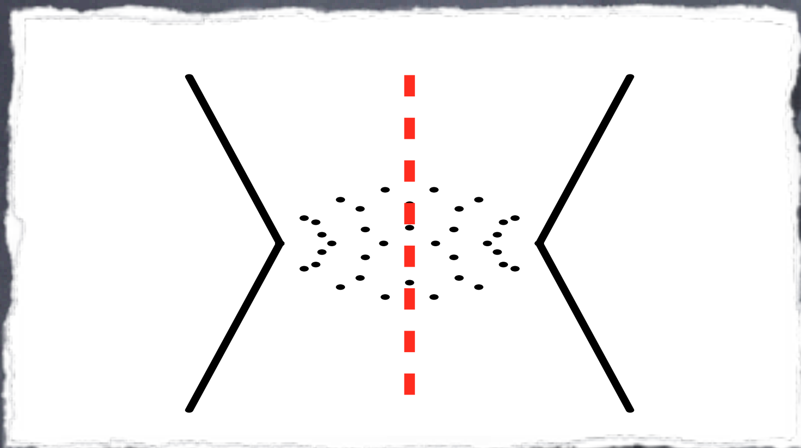

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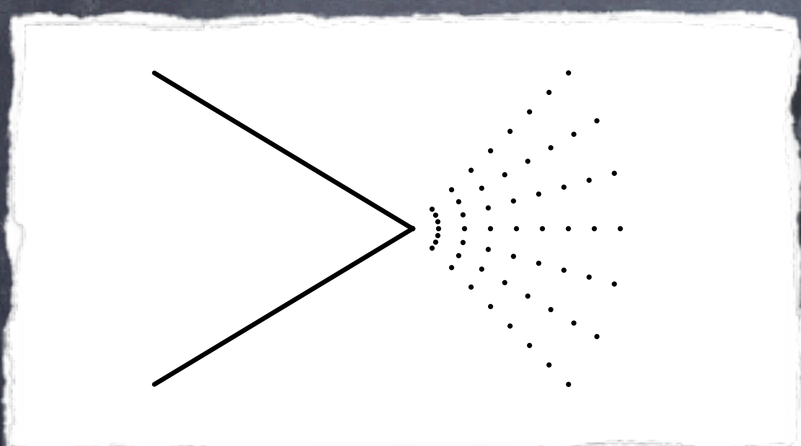

1. Compute σ (n massles particles)
2. Analytic continuation n → Δ

H. Georgi (2007)

Coupling with SM

$$\frac{1}{\Lambda^{\Delta}} F_{\mu\nu} F^{\mu\nu} \mathcal{O}_u$$

$\rightarrow$

$$\partial A \partial A \mathcal{O}_u$$
$$\partial A \partial Z \mathcal{O}_u$$

S. Kathrein, SK, M. Strassler (2010)

$$\partial G \partial G \mathcal{O}_u$$

A. Delgado, M. Strassler (2010)

1 < Δ < 2

$\rightarrow$ dimension 5 or higher

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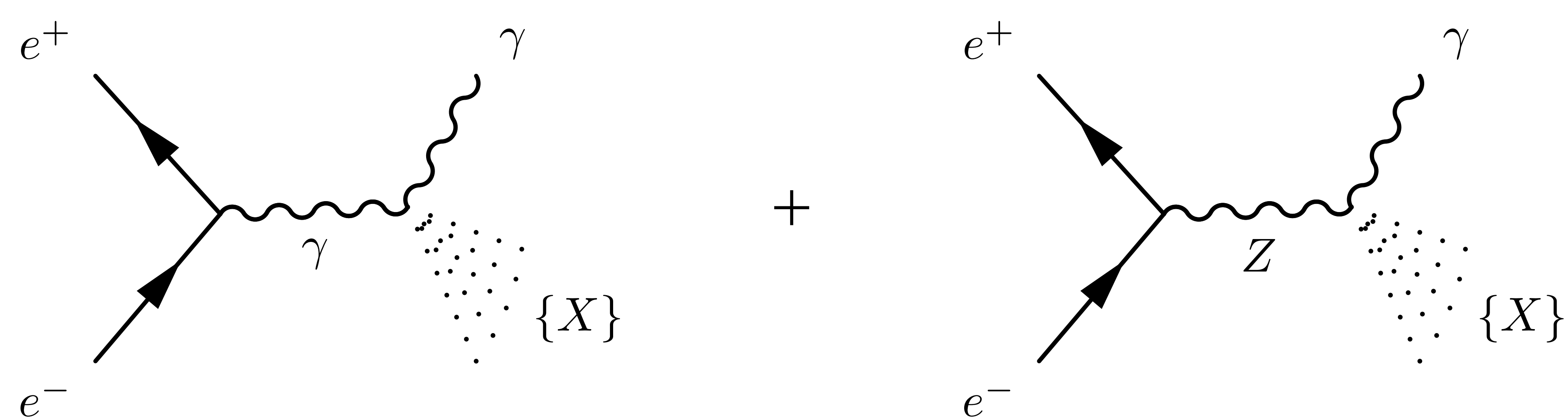
Diagrams



$$\frac{d^2\sigma}{dq\,d\cos\theta} = \frac{(4\pi)^{1-2\Delta}}{\Gamma(\Delta-1)\Gamma(\Delta)} A(\Lambda_{\gamma Z}, \Lambda_\gamma) e^2 q^3 s^{\Delta-3} (1 - 2\frac{q}{\sqrt{s}})^{\Delta-2} (1 + \cos^2\theta)$$

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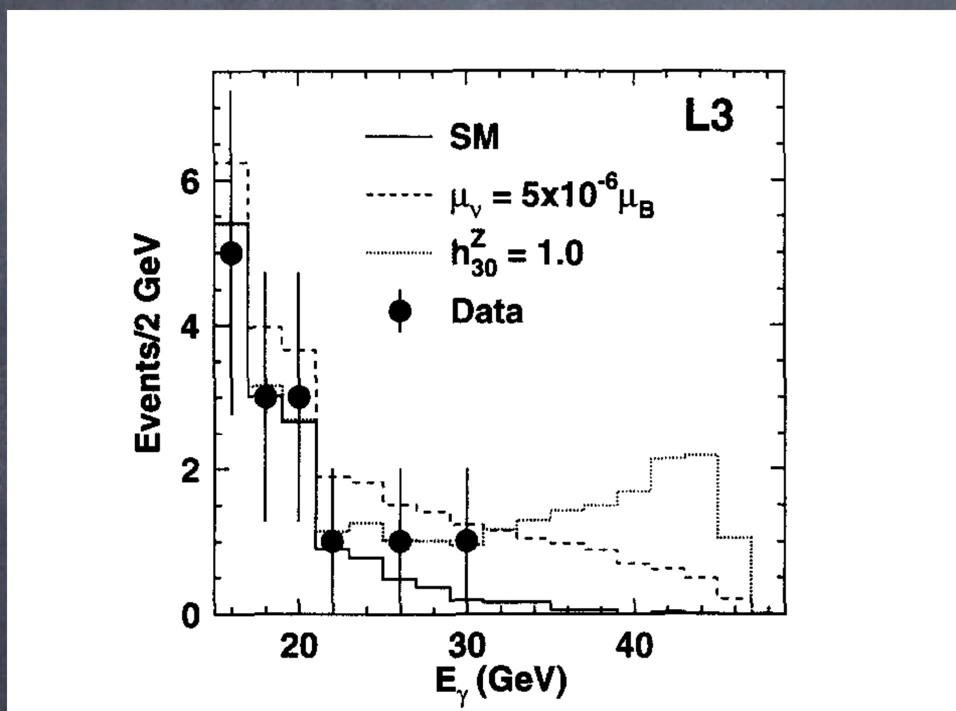
LEP I & II

(ALEPH, OPAL, DELPHI & L3)

LEP I ($\sqrt{s}$ = 90 GeV)

LEP II ($\sqrt{s}$ = 190-210 GeV)



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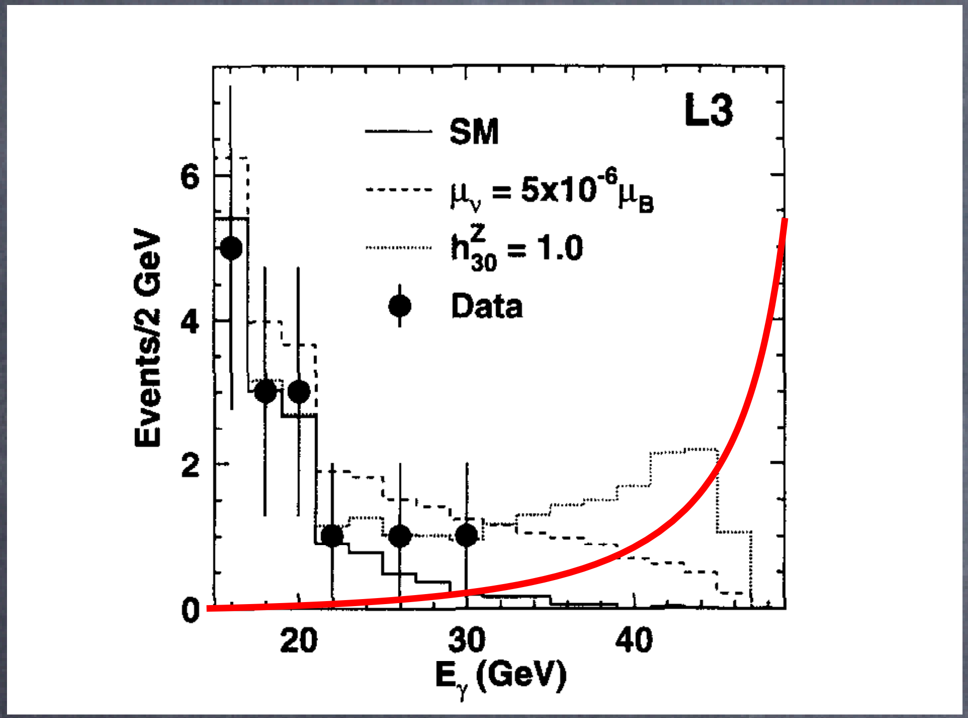

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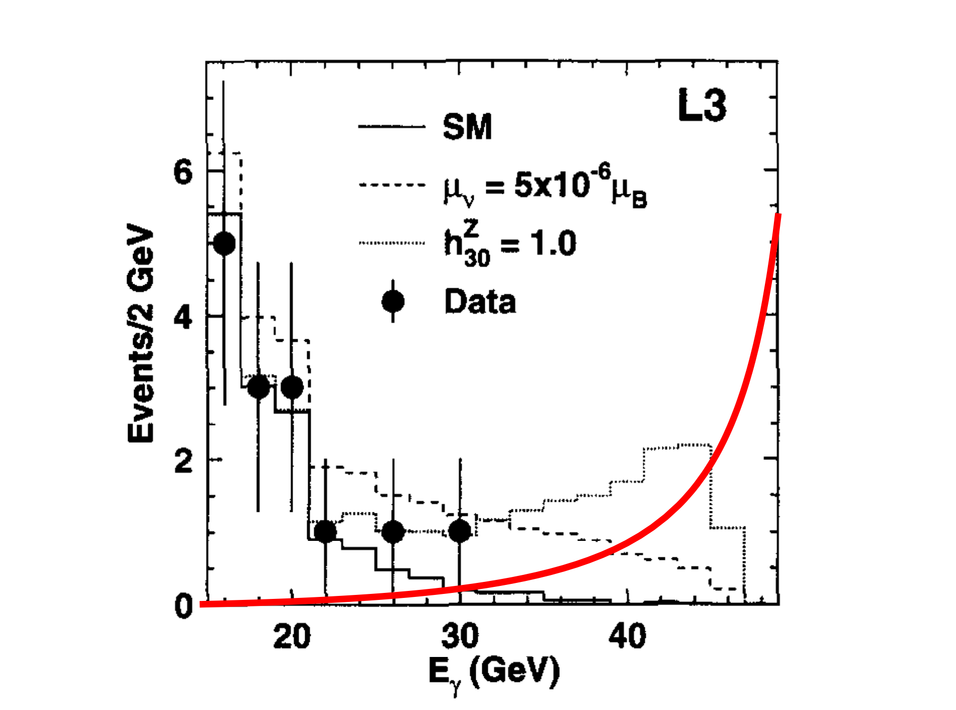

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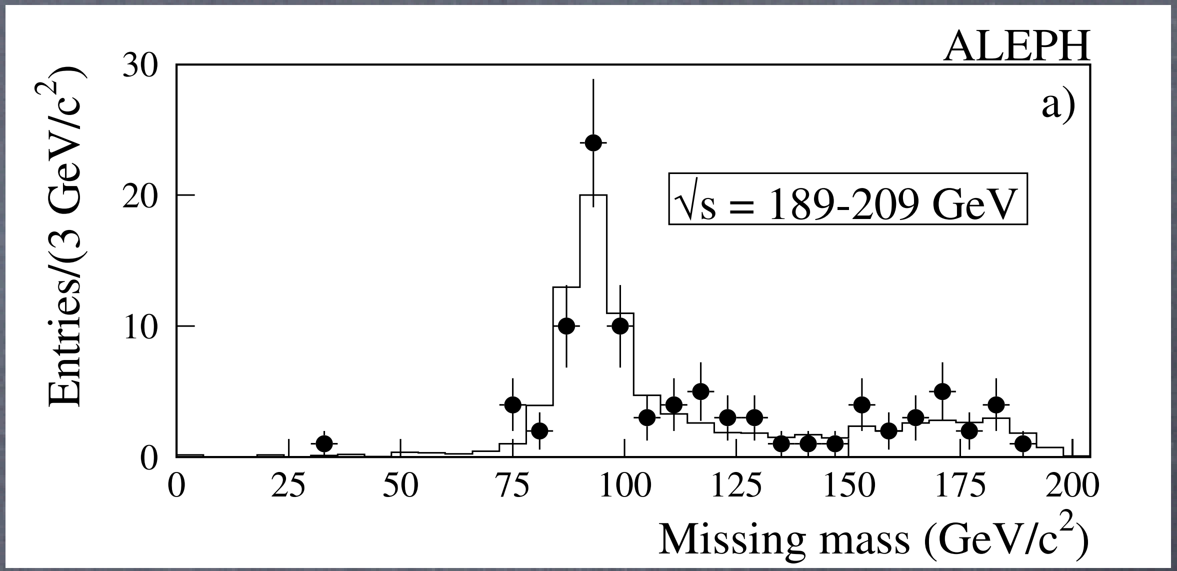

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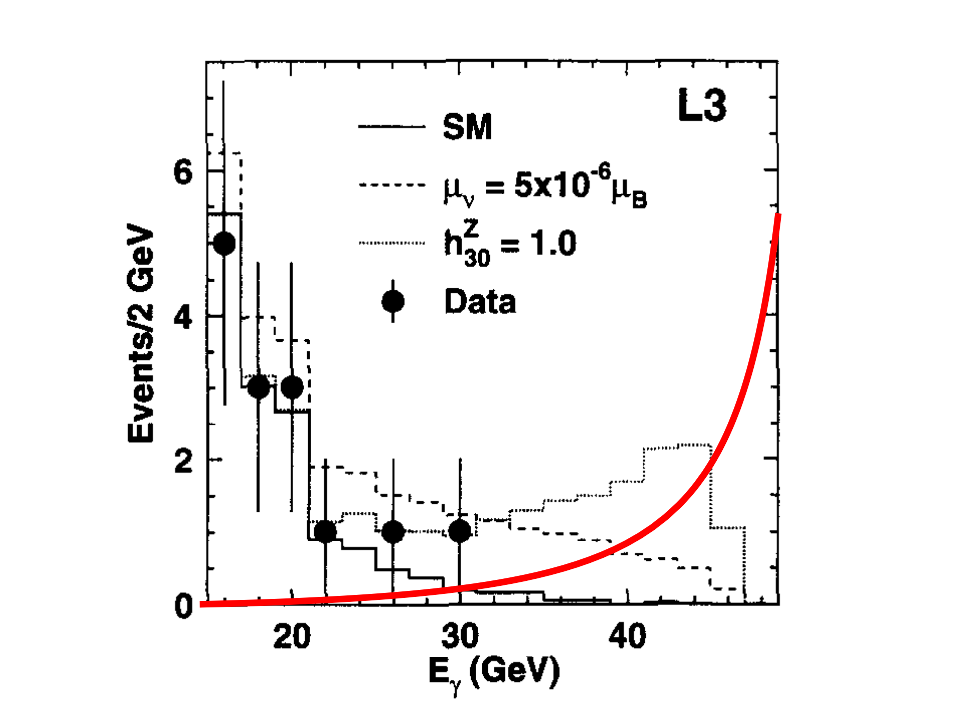

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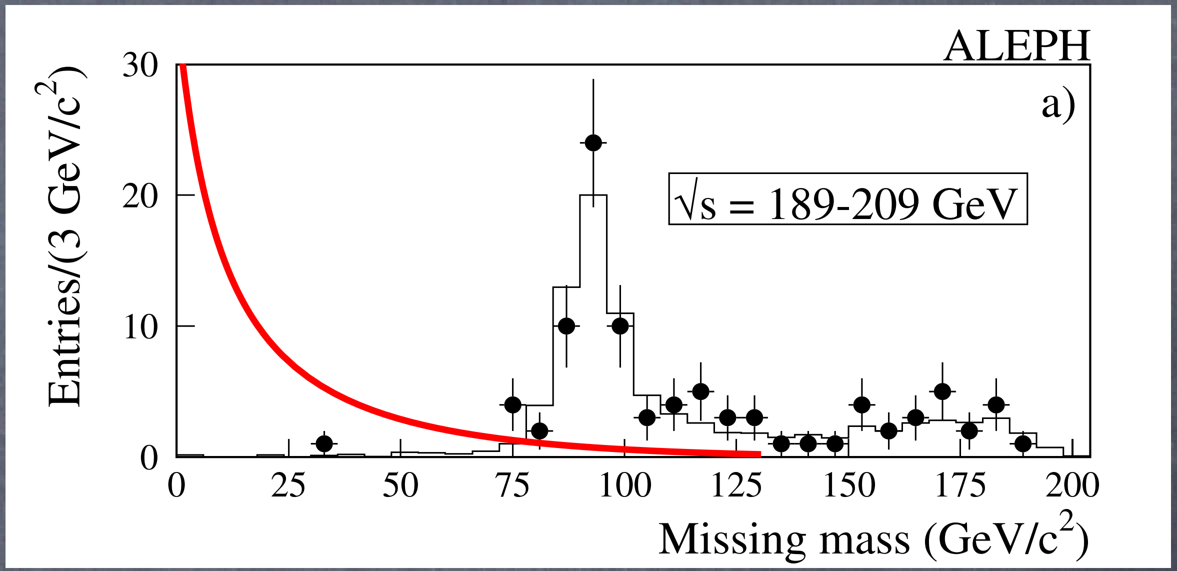

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Experimental Bounds

95% CL (TeV)

Δ	Λ_Z	Λ_γ
1	69.5	25.2
1.01	59.0	23.0
1.05	40.7	13.2
1.1	26.6	8.0
1.2	12.7	3.6
1.3	6.8	2.0
1.4	4.0	1.2
1.5	2.5	0.79
1.6	1.6	0.57
1.7	1.1	0.41
1.8	0.80	0.30
1.9	0.60	0.24
2	0.46	0.19

$$\frac{1}{\Lambda_Z}\partial A \partial Z \mathcal{O}_u$$
$$\frac{1}{\Lambda_\gamma}\partial A \partial A \mathcal{O}_u$$

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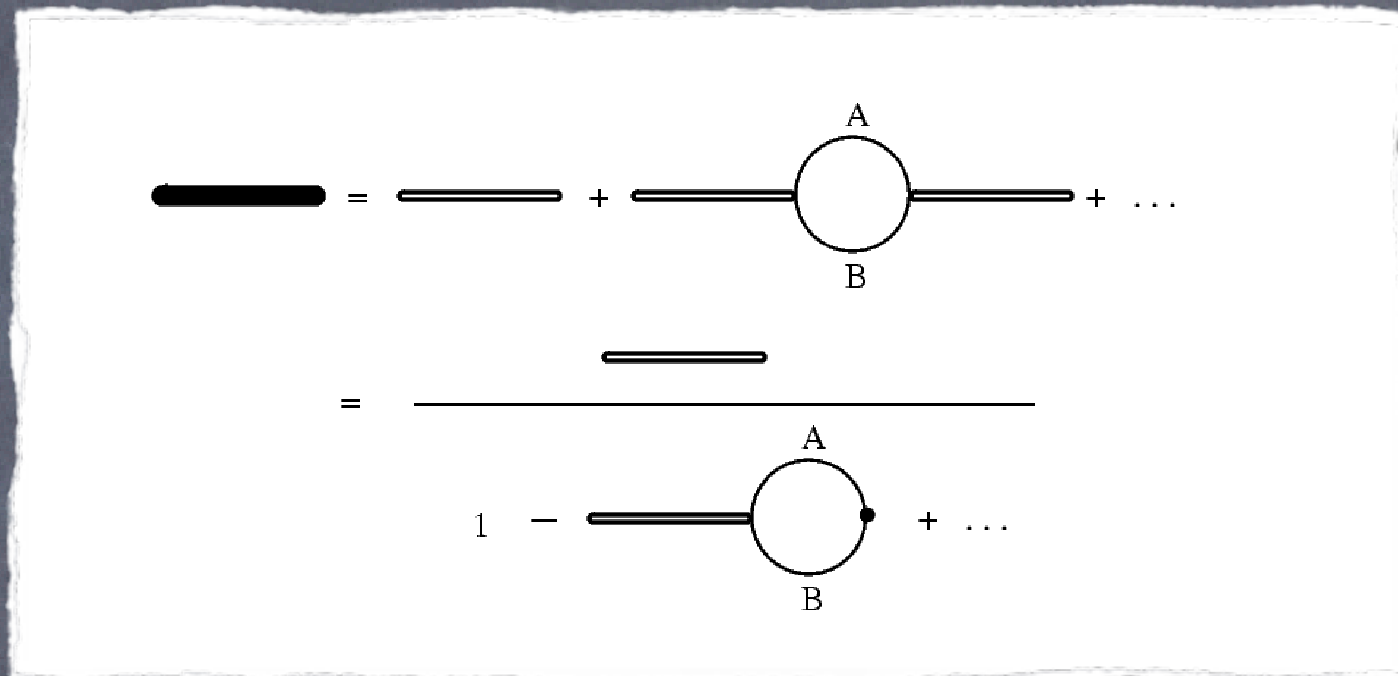
Theory Bounds



A. Delgado, M. Strassler (2009)

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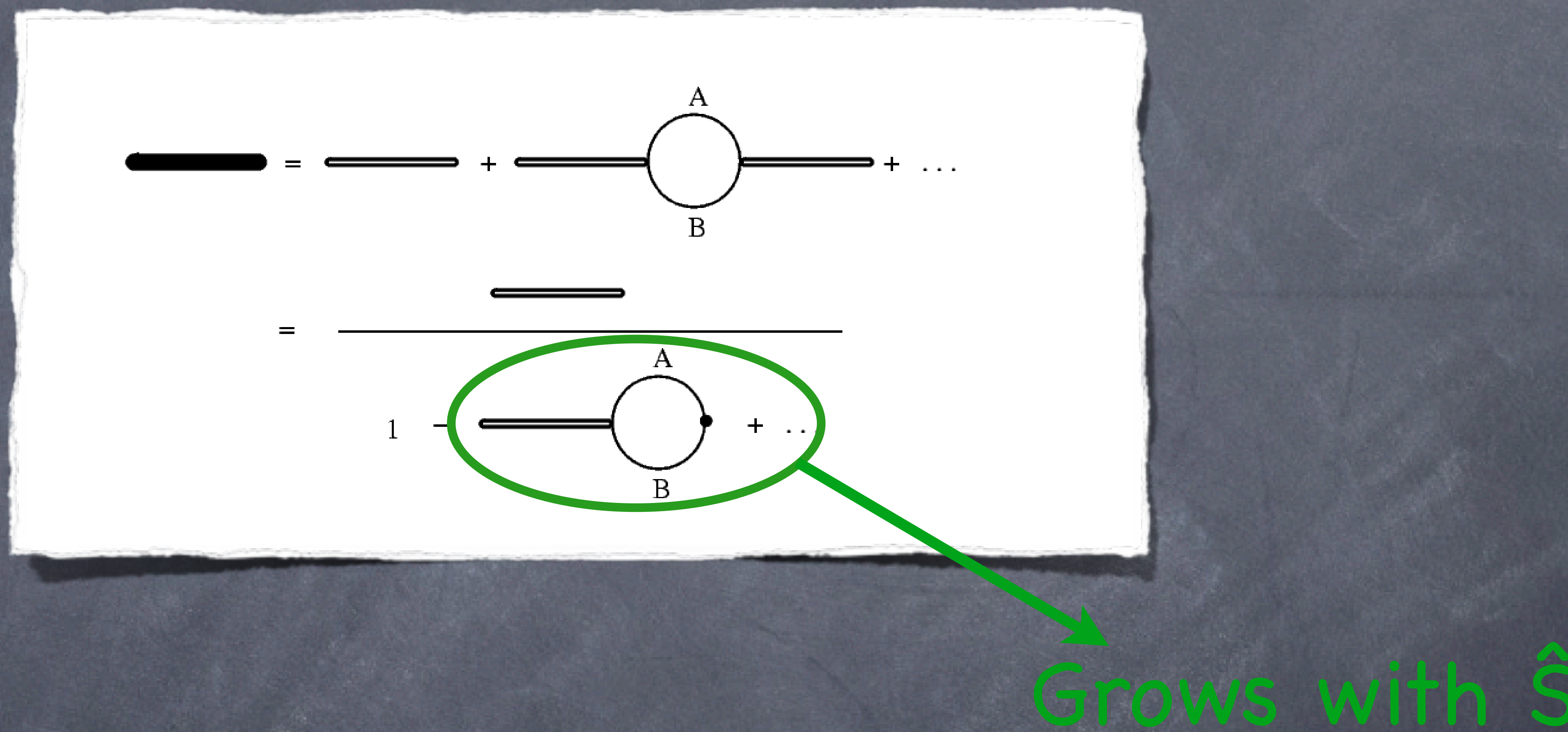
Theory Bounds



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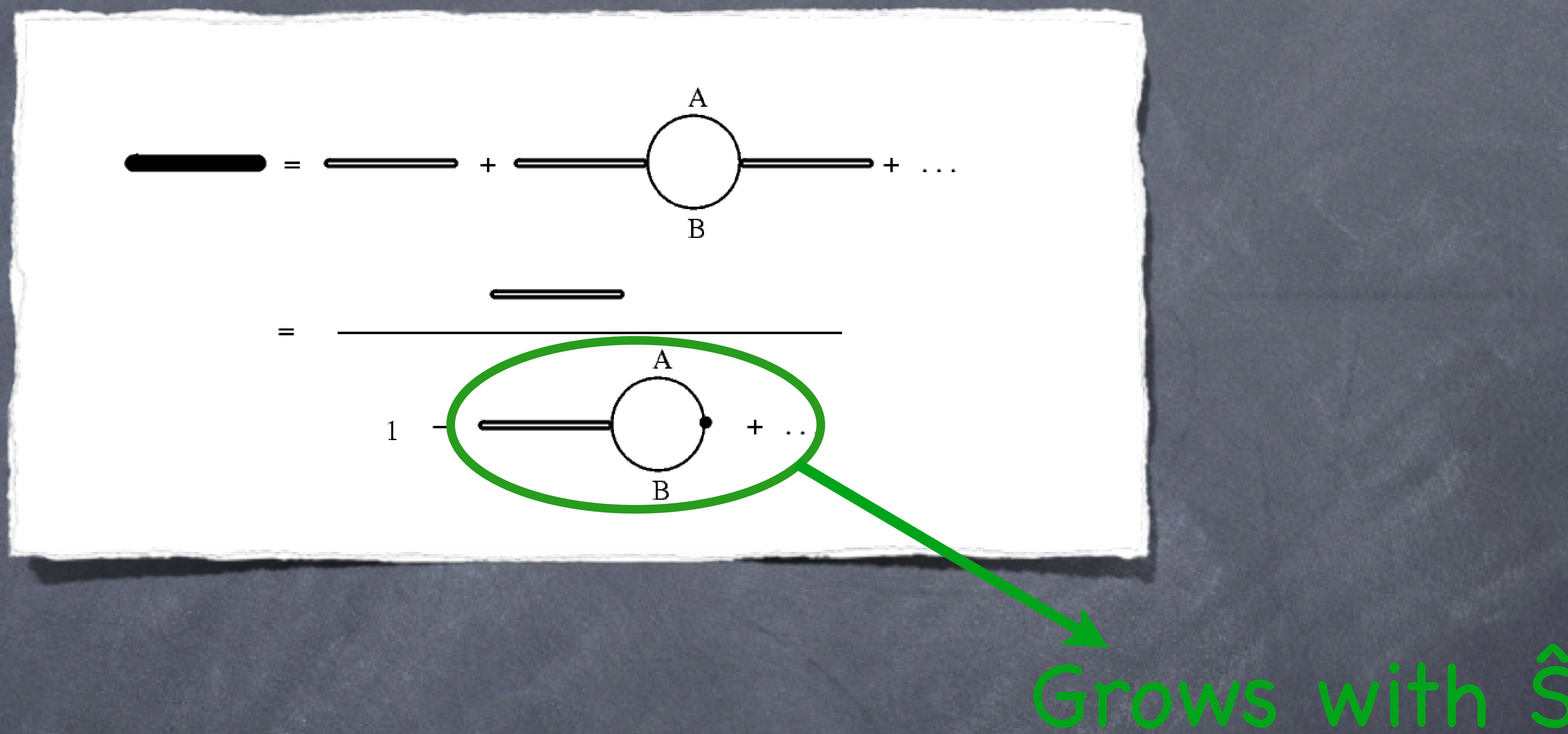
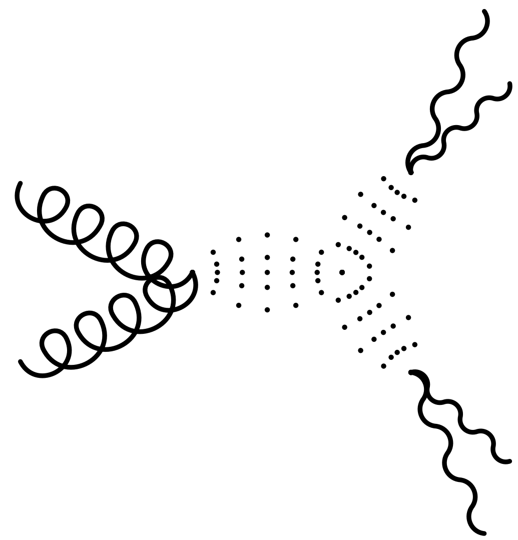


Conformal invariance must break down in the UV

A. Delgado, M. Strassler (2009)

Application: $gg \to 4\gamma$



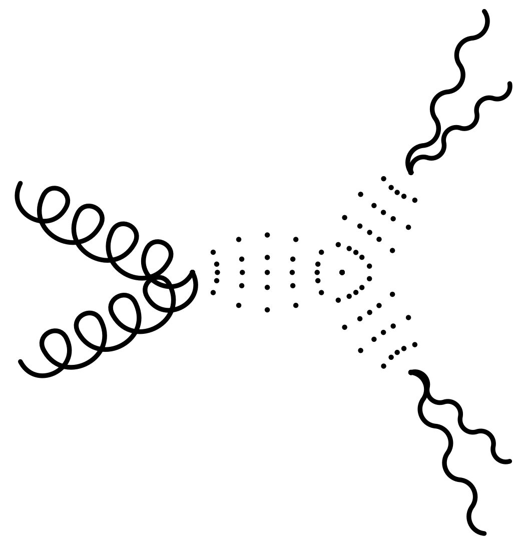
$$\sim \quad \left(\frac{C_3}{\Lambda_g^{\Delta_g}\Lambda_\gamma^{2\Delta_\gamma}}\right)^2$$

$$\sim \quad \langle \mathcal{O}_g \mathcal{O}_\gamma \mathcal{O}_\gamma \rangle$$

J. L. Feng, A. Rajaraman and H. Tu (2008)

Simon Knapen, Rutgers University

Application: gg → 4γ



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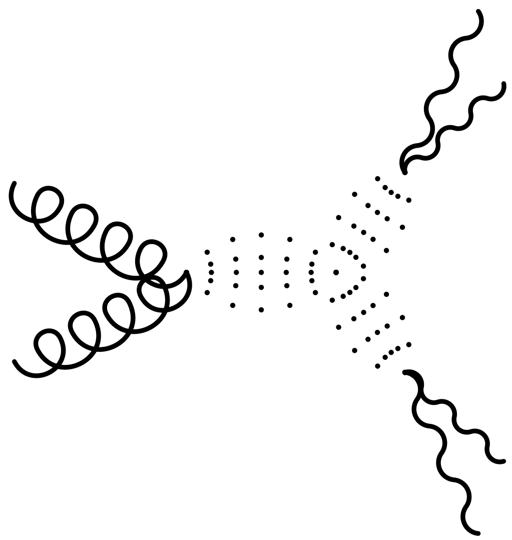

$$\sim \left(\frac{C_3}{\Lambda_g^{\Delta_g}\Lambda_\gamma^{2\Delta_\gamma}}\right)^2$$

$$\sim \langle \mathcal{O}_g \mathcal{O}_\gamma \mathcal{O}_\gamma \rangle$$

J. L. Feng, A. Rajaraman and H. Tu (2008)

Bound individually:

Λ_g ➜ Tevatron (A. Delgado, M. Strassler (2009))

Λ_γ ➜ LEP (S. Kathrein, SK, M. Strassler (2010))

C_3 ➜ Unitarity, Conformal symmetry (F. Caracciolo and S. Rychkov (2010))

Only for $1 < \Delta_\gamma < 1.7$

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Unitarity bound

$1 < \Delta_g < 2$
$1.7 < \Delta_\gamma < 2$ $\longrightarrow$ No bound on C_3 available

A. Delgado, M. Strassler (2009)

Unitarity bound

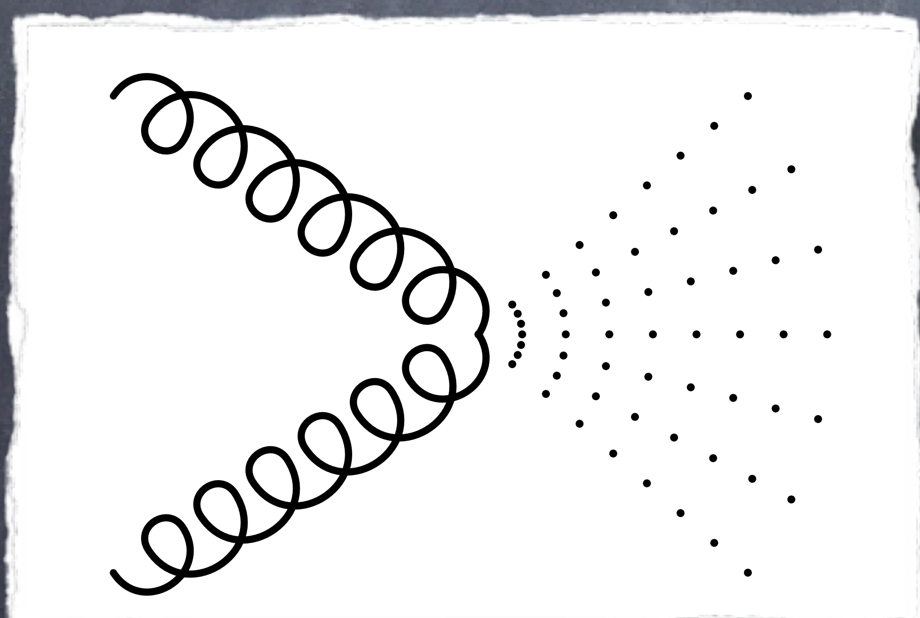
$1 < \Delta_g < 2$
$1.7 < \Delta_\gamma < 2$ $\longrightarrow$ No bound on C_3 available

No process that involves the hidden sector can have a rate that exceeds the rate of all such processes

A. Delgado, M. Strassler (2009)

Unitarity bound

$1 < \Delta_g < 2$
$1.7 < \Delta_\gamma < 2$ → No bound on C_3 available



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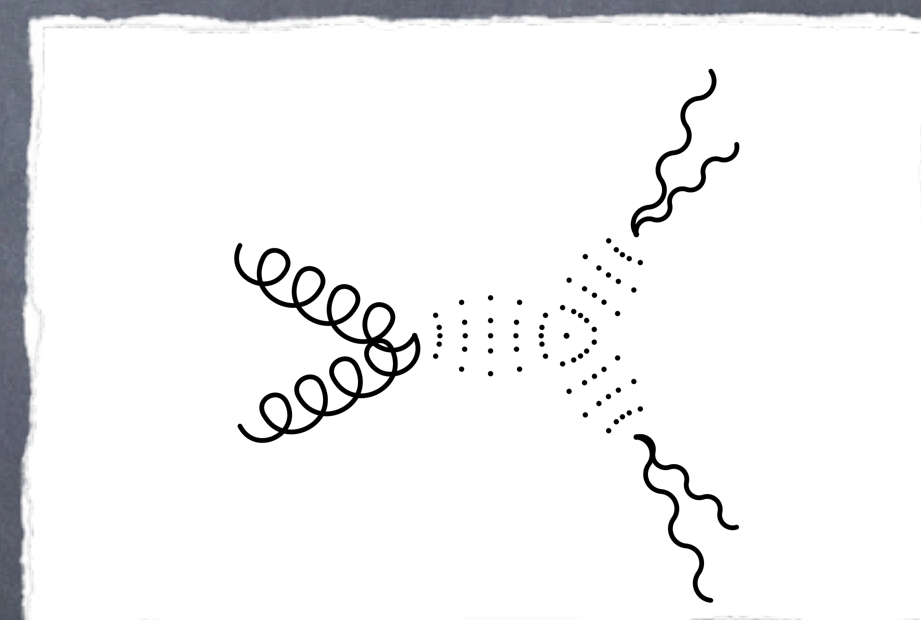

A. Delgado, M. Strassler (2009)

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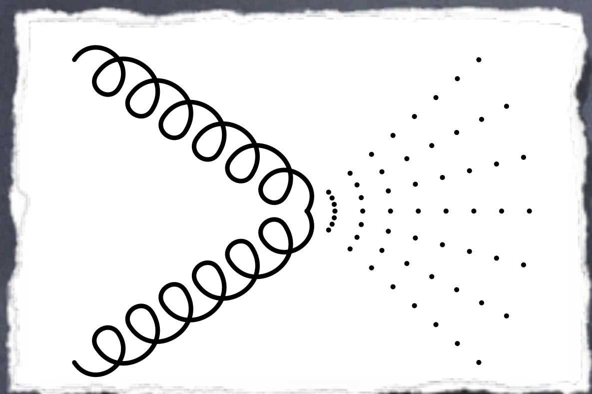
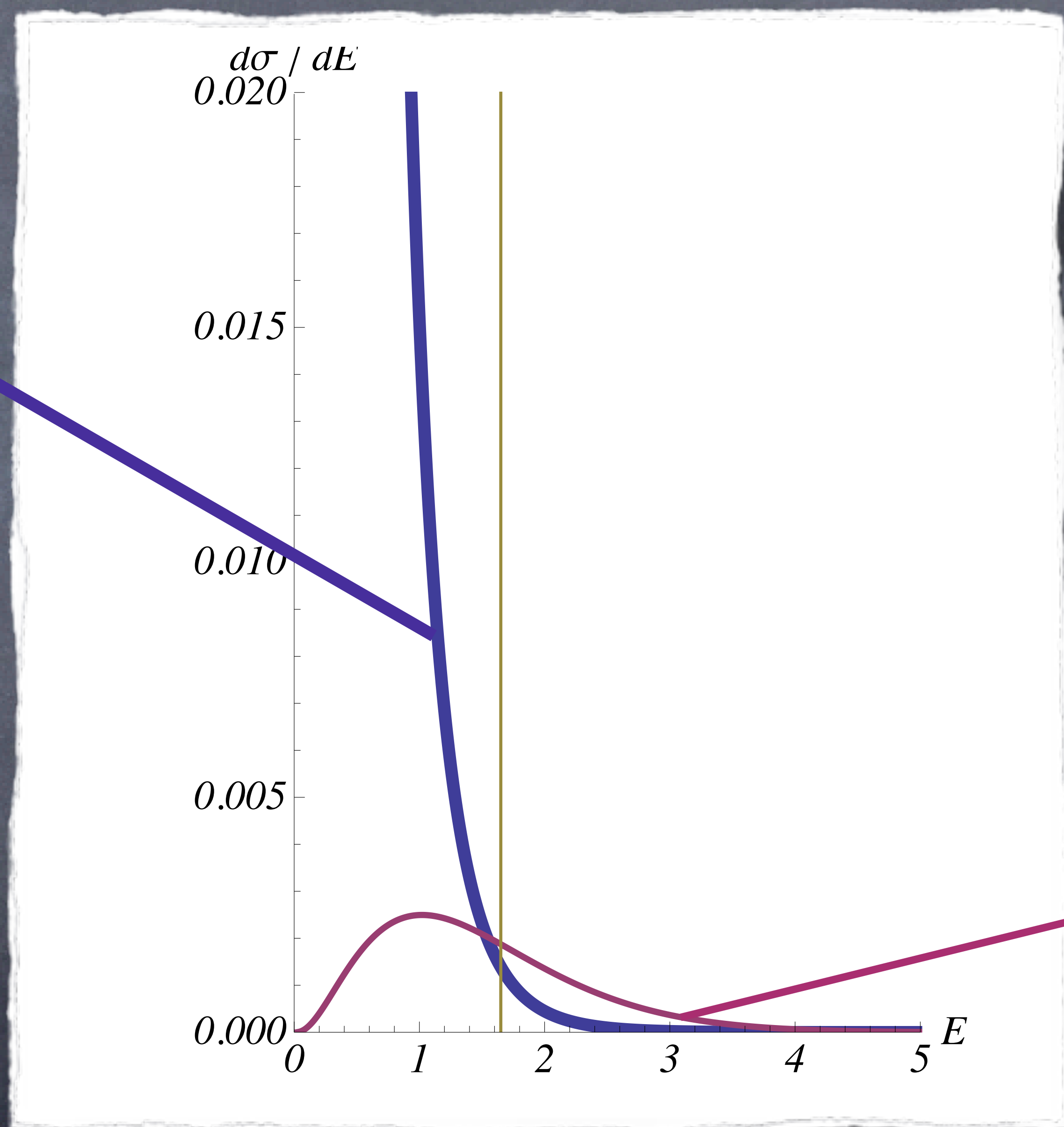
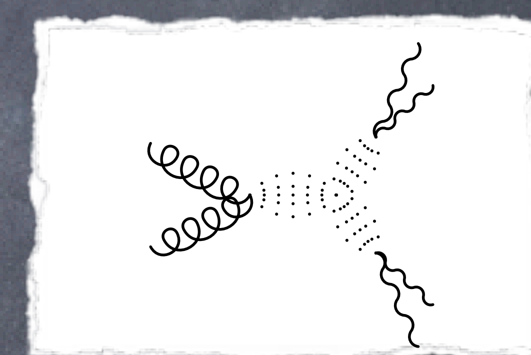
Unitarity bound







A. Delgado, M. Strassler (2009)

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Bound on $\sigma_{gg \to 4\gamma}$ for 14 TeV LHC

$\Delta_g \backslash \Delta_\gamma$	1.05	1.1	1.2	1.3	1.4	1.5	1.6	1.7	1.8	1.9	2.0
1.05	2.7×10^{-6}	2.7×10^{-5}	4.8×10^{-4}	0.010	0.093	0.62	**1.1**	**1.7**	*3.8*	*2.3*	*1.4*
1.1	5.1×10^{-6}	5.2×10^{-5}	6.7×10^{-4}	0.014	0.13	0.89	**1.4**	**1.6**	*9.6*	*5.9*	*3.7*
1.2	1.5×10^{-5}	1.4×10^{-4}	1.3×10^{-3}	0.023	0.37	2.4	**2.3**	**1.7**	*2.3*	*1.4*	*7.1*
1.3	3.7×10^{-5}	$\mathbf{2.8 \times 10^{-4}}$	$\mathbf{3.2 \times 10^{-3}}$	**0.031**	**0.33**	**1.7**	**1.2**	**0.91**	*16.*	*9.3*	*5.4*
1.4	$\mathbf{3.3 \times 10^{-5}}$	$\mathbf{2.5 \times 10^{-4}}$	$\mathbf{2.3 \times 10^{-3}}$	**0.023**	**0.24**	**1.2**	**0.73**	**0.56**	*12.*	*7.1*	*4.5*
1.5	$\mathbf{3.6 \times 10^{-5}}$	$\mathbf{2.4 \times 10^{-4}}$	$\mathbf{2.8 \times 10^{-3}}$	**0.025**	**0.19**	**0.78**	**0.57**	**0.37**	*9.3*	*5.4*	*3.2*
1.6	$\mathbf{3.6 \times 10^{-5}}$	$\mathbf{2.6 \times 10^{-4}}$	$\mathbf{2.3 \times 10^{-3}}$	**0.021**	**0.16**	**0.55**	**0.48**	**0.31**	*7.1*	*4.7*	*2.5*
1.7	$\mathbf{4.7 \times 10^{-5}}$	$\mathbf{2.9 \times 10^{-4}}$	$\mathbf{2.7 \times 10^{-3}}$	**0.024**	**0.16**	**0.50**	**0.35**	**0.26**	*5.4*	*3.2*	*2.0*
1.8	$\mathbf{4.4 \times 10^{-5}}$	$\mathbf{2.2 \times 10^{-4}}$	$\mathbf{1.7 \times 10^{-3}}$	**0.022**	**0.20**	**0.38**	**0.32**	**0.23**	*4.2*	*2.5*	*1.5*
1.9	$\mathbf{3.4 \times 10^{-5}}$	$\mathbf{1.6 \times 10^{-4}}$	$\mathbf{1.5 \times 10^{-3}}$	**0.014**	**0.15**	**0.36**	**0.29**	**0.23**	*3.2*	*2.0*	*1.2*
2.0	$\mathbf{2.7 \times 10^{-5}}$	$\mathbf{1.3 \times 10^{-4}}$	$\mathbf{8.7 \times 10^{-4}}$	**0.013**	**0.14**	**0.35**	**0.31**	**0.24**	*2.5*	*1.5*	*0.96*

Simon Knapen, Rutgers University

Bound on $\sigma_{gg\to 4\gamma}$ for 14 TeV LHC

$\Delta_g \diagdown \Delta_\gamma$	1.05	1.1	1.2	1.3	1.4	1.5	1.6	1.7	1.8	1.9	2.0
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1.2	1.5×10^{-5}	1.4×10^{-4}	1.3×10^{-3}	0.023	0.37	2.4	**2.3**	**1.7**	*2.3*	*1.4*	*7.1*
1.3	3.7×10^{-5}	$\mathbf{2.8 \times 10^{-4}}$	$\mathbf{3.2 \times 10^{-3}}$	**0.031**	**0.33**	**1.7**	**1.2**	**0.91**	*16.*	*9.3*	*5.4*
1.4	$\mathbf{3.3 \times 10^{-5}}$	$\mathbf{2.5 \times 10^{-4}}$	$\mathbf{2.3 \times 10^{-3}}$	**0.023**	**0.24**	**1.2**	**0.73**	**0.56**	*12.*	*7.1*	*4.5*
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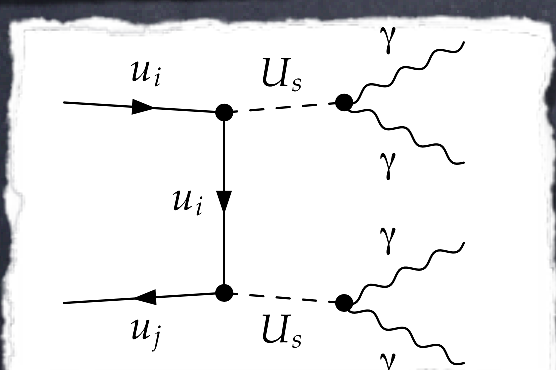


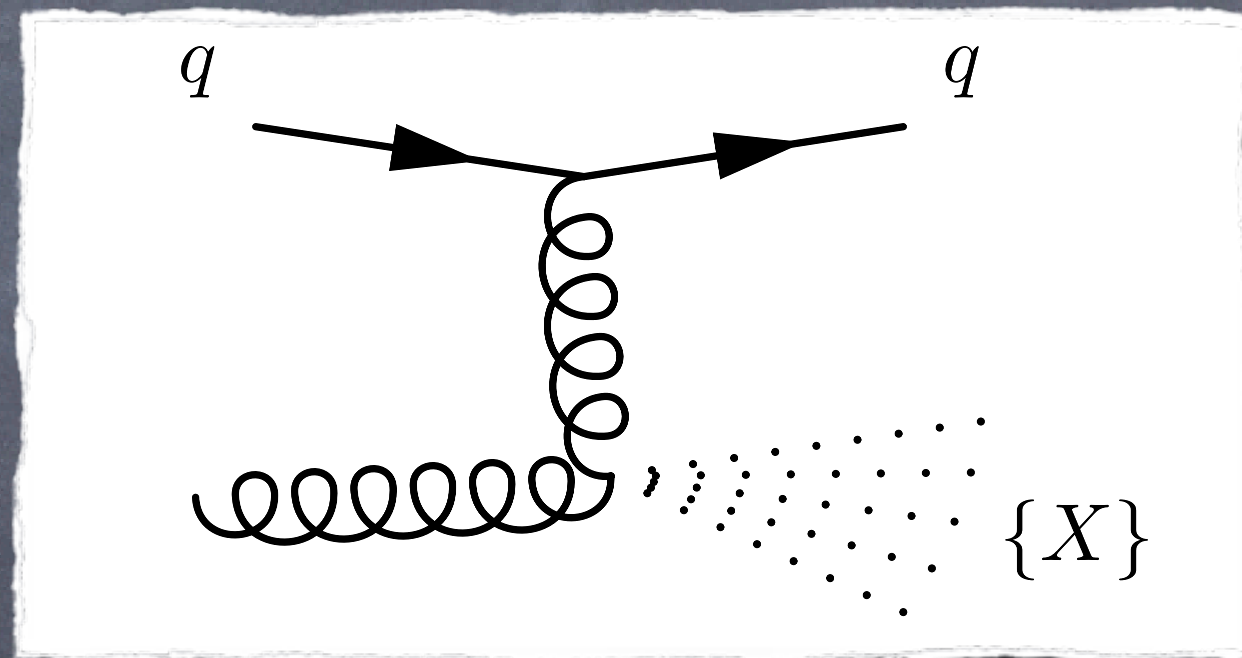
Not accounted for here

T. Aliev, M. Frank, I. Turan (2009)

Simon Knapen, Rutgers University

Outlook

Discovery through Unparticle production (Jet + MET)



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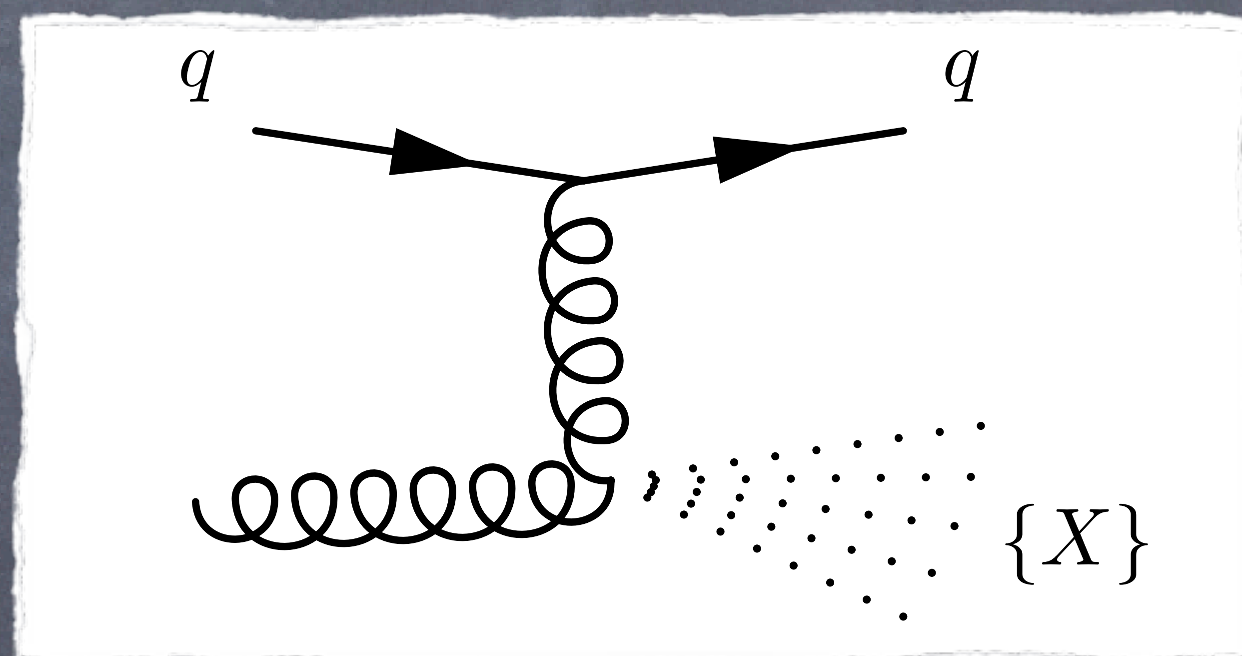

$$\hat{\sigma} \sim \frac{1}{\hat{s}}\left(\frac{\hat{s}}{\Lambda^2}\right)^{\Delta}$$

→ Bounds improve rapidly with increasing $\hat{s}$

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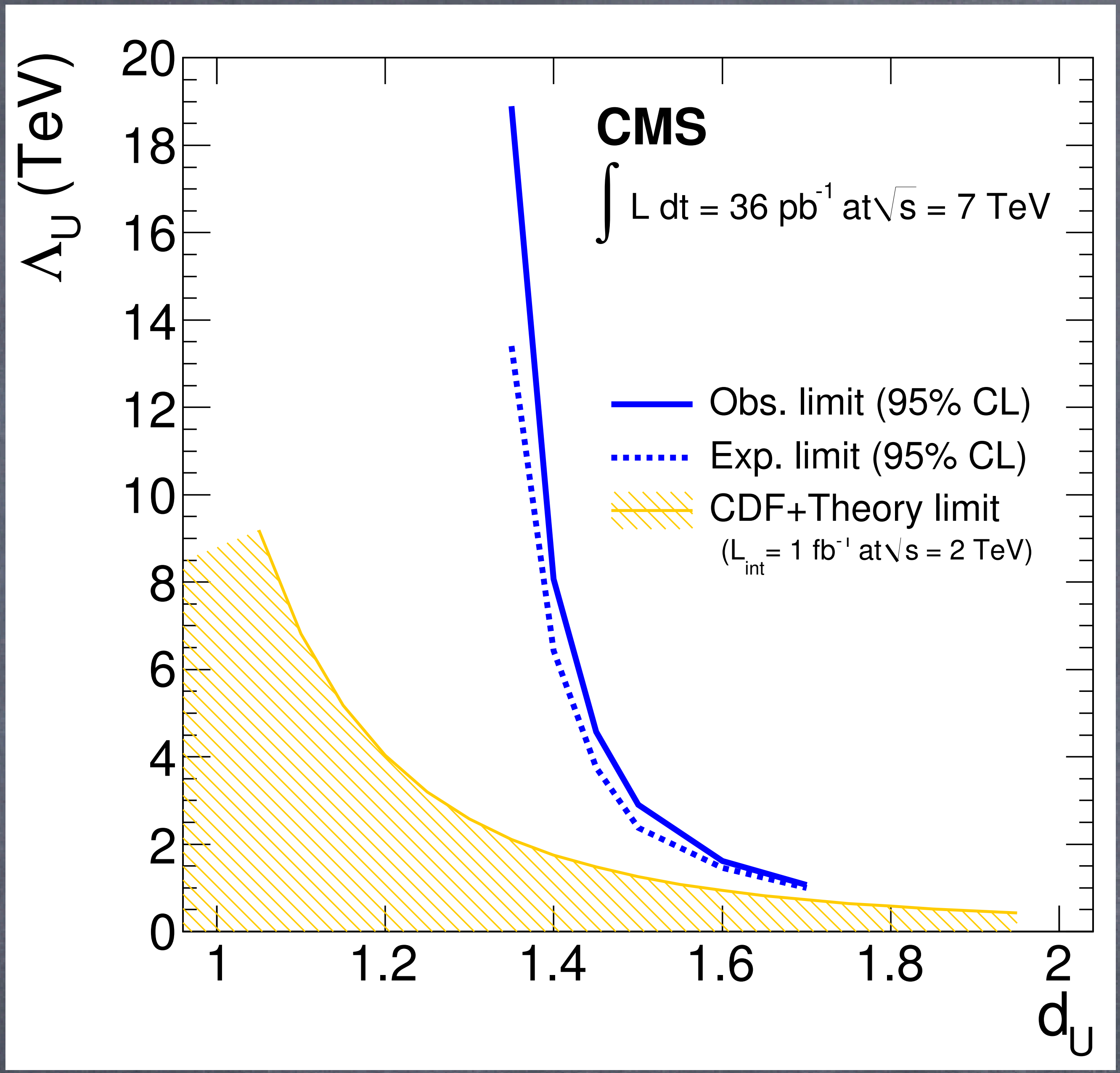

CMS collaboration, June 2011

Simon Knapen, Rutgers University

Conclusions

- Bounds on unparticle interactions with electro-weak gauge bosons range from $\Lambda \sim$ 200 GeV - 50 TeV
- Four photon production through 3-points function can not be discovery channel
- Our bounds will improve dramatically with LHC data

SM couplings

$$\frac{1}{\Lambda^{\Delta-2}} H H^\dagger \mathcal{O}_u, \quad \frac{1}{\Lambda^{\Delta-1}} \bar{f} H f' \mathcal{O}_u, \quad \frac{1}{\Lambda^{\Delta-1}} \bar{f} H \gamma_5 f' \mathcal{O}_u, \quad \frac{1}{\Lambda^{\Delta}} G_{\alpha\beta} G^{\alpha\beta} \mathcal{O}_u,$$
$$\frac{1}{\Lambda^{\Delta-1}} \bar{f} \gamma_\mu f \mathcal{O}_u^\mu, \quad \frac{1}{\Lambda^{\Delta-1}} \bar{f} \gamma_\mu \gamma_5 f \mathcal{O}_u^\mu,$$
$$-\frac{1}{4} \frac{1}{\Lambda^{\Delta}} \bar{f} \left(\gamma_\mu \overleftrightarrow{D}_\nu + \gamma_\nu \overleftrightarrow{D}_\mu \right) f \mathcal{O}_u^{\mu\nu}, \quad \frac{1}{\Lambda^{\Delta}} G_{\mu\alpha} G_\nu{}^\alpha \mathcal{O}_u^{\mu\nu}$$

(Unitarity)

$$\begin{aligned} \Delta_{\mathcal{O}_u} &\geq 1 \\ \Delta_{\mathcal{O}_u^\mu} &\geq 3 \\ \Delta_{\mathcal{O}_u^{\mu\nu}} &\geq 4 \end{aligned}$$

G. Mack (1977)
B. Grinstein, K. Intriligator, I Rothstein (2008)

Simon Knapen, Rutgers University

SM couplings

$$\frac{1}{\Lambda^{\Delta-2}} H H^\dagger \mathcal{O}_u, \quad \frac{1}{\Lambda^{\Delta-1}} \bar{f} H f' \mathcal{O}_u, \quad \frac{1}{\Lambda^{\Delta-1}} \bar{f} H \gamma_5 f' \mathcal{O}_u, \quad \frac{1}{\Lambda^{\Delta}} G_{\alpha\beta} G^{\alpha\beta} \mathcal{O}_u,$$

$$\frac{1}{\Lambda^{\Delta-1}} \bar{f} \gamma_\mu f \mathcal{O}_u^\mu, \quad \frac{1}{\Lambda^{\Delta-1}} \bar{f} \gamma_\mu \gamma_5 f \mathcal{O}_u^\mu,$$

$$-\frac{1}{4} \frac{1}{\Lambda^{\Delta}} \bar{f} \left(\gamma_\mu \overleftrightarrow{D}_\nu + \gamma_\nu \overleftrightarrow{D}_\mu \right) f \mathcal{O}_u^{\mu\nu}, \quad \frac{1}{\Lambda^{\Delta}} G_{\mu\alpha} G_\nu{}^\alpha \mathcal{O}_u^{\mu\nu}$$

(Unitarity)

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$$\left.\begin{aligned} &\partial A \partial A \mathcal{O}_u \\ &\partial A \partial Z \mathcal{O}_u \end{aligned}\right\} \text{S. Kathrein, SK, M. Strassler (2010)}$$

$$\partial G \partial G \mathcal{O}_u$$

A. Delgado, M. Strassler (2010)

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Simon Knapen, Rutgers University

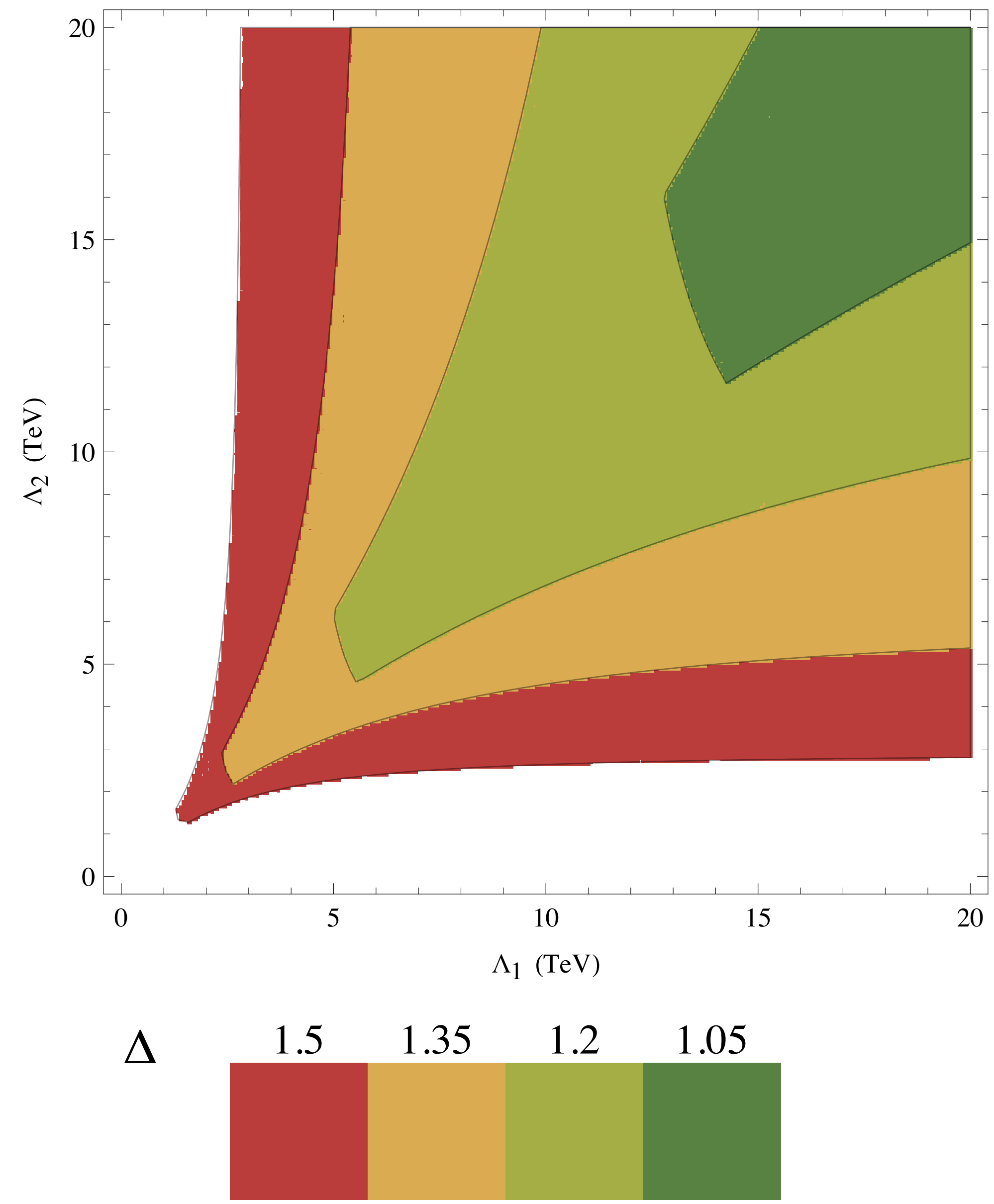
Coupling with W`s

$$\frac{\lambda_1}{\Lambda_1^\Delta} B_{\alpha\beta} B^{\alpha\beta} \mathcal{O}_u + \frac{\lambda_2}{\Lambda_2^\Delta} W^3_{\alpha\beta} W^{3\alpha\beta} \mathcal{O}_u$$

$$\Downarrow$$

$$\frac{\lambda_{\gamma Z}}{\Lambda_{\gamma Z}^\Delta} \equiv \frac{\lambda_2}{\Lambda_2^\Delta} - \frac{\lambda_1}{\Lambda_1^\Delta}$$

$$\frac{\lambda_{\gamma}}{\Lambda_{\gamma}^\Delta} \equiv c_\theta^2 \frac{\lambda_1}{\Lambda_1^\Delta} + s_\theta^2 \frac{\lambda_2}{\Lambda_2^\Delta}$$



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